EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-INTC-2006-016
INTC-P-209

Angular distributions in the neutron-induced fission of actinides

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Motivation

In 2003 the n_TOF Collaboration performed the fission cross section measurement of several actinides (^{232}Th, ^{233}U, ^{234}U, ^{237}Np) at the n_TOF facility using an experimental setup made of Parallel Plate Avalanche Counters (PPAC). The method based on the detection of the 2 fragments in coincidence allowed to clearly disentangle the fission reactions among other types of reactions occurring in the spallation domain [1]. We have been therefore able to cover the very broad neutron energy range 1eV-1GeV, taking full benefit of the unique characteristics of the n_TOF facility. Figure 1 shows an example obtained in the case of ^{237}Np where the n_TOF measurement showed that the cross section was underestimated by a large factor in the resonance region.

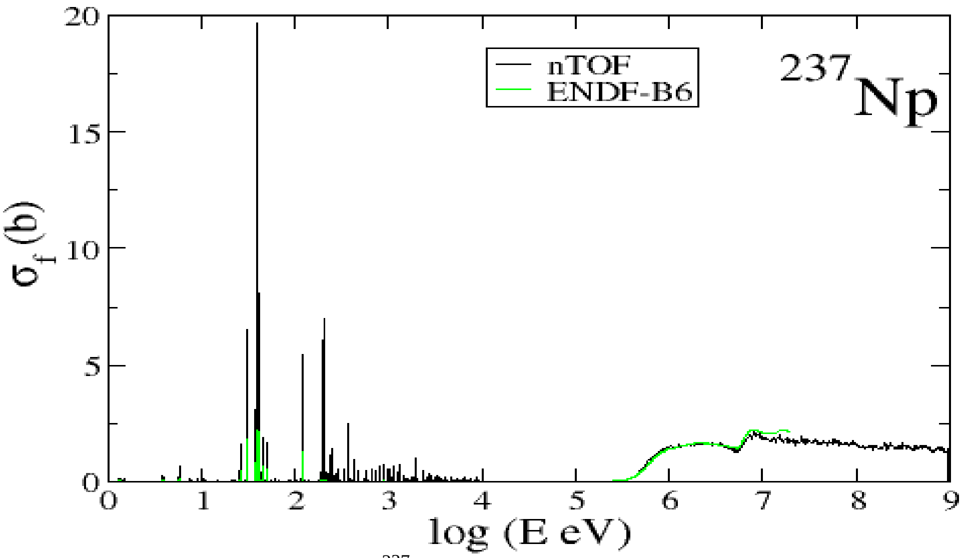

Figure 1: Comparison of the ^{237}Np fission cross sections measured at nTOF (relative to ^{235}U) and the ENDF evaluation from previous experiments.

When processing the data to extract the cross section an important aspect must be considered: the angular distribution of the fission fragments [2]. As shown in Figure 2, our set up is made of a stack of PPACs interleaved with the targets.

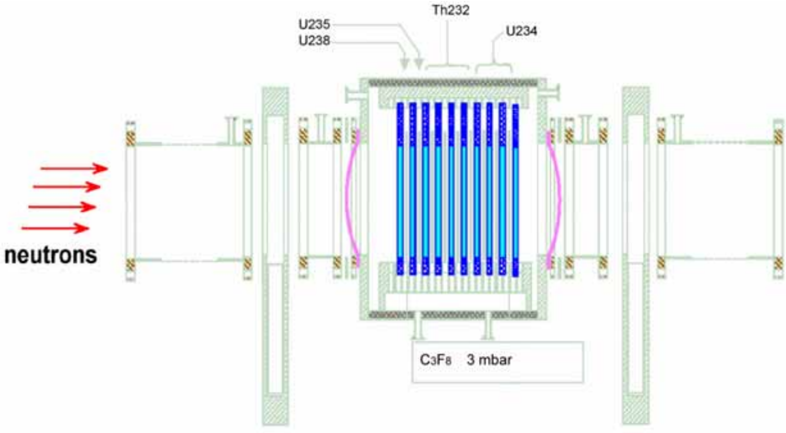

Figure 2: Schematic view of the PPAC and target stack.

The requirement of detection of the two fragments in coincidence puts severe constraints on the thickness of the detector electrodes and the backing of the target samples. Although we performed the best achievement done up to now in this respect, the thickness of those components induces a reduction of the detection efficiency for fragments emitted beyond 45° with respect to the beam axis. This would not be a major concern because this angular limitation can be well calibrated owing to the XY localisation capability of the detectors which allows to reconstruct the fission angle and correct for its limitation. However, this is only true if the angular distribution is well-known. Our setup is able to measure the angular distribution between 0° and 45° which can be useful to reveal possible anisotropies but the full angular distribution must be covered to derive an accurate efficiency correction and thus to obtain the cross section from the measurement.

The fission angular distributions have often been measured in the past and consistent data exist for isotopes mentioned above, below a few MeV. However, the measurements are very scarce or discordant above this limit, with a situation of almost unknown data above 20 MeV. This is illustrated for ^{237}Np in Figure 3, which displays the energy variation of the anisotropy, defined as the ratio of differential cross sections at 0° to 90°.

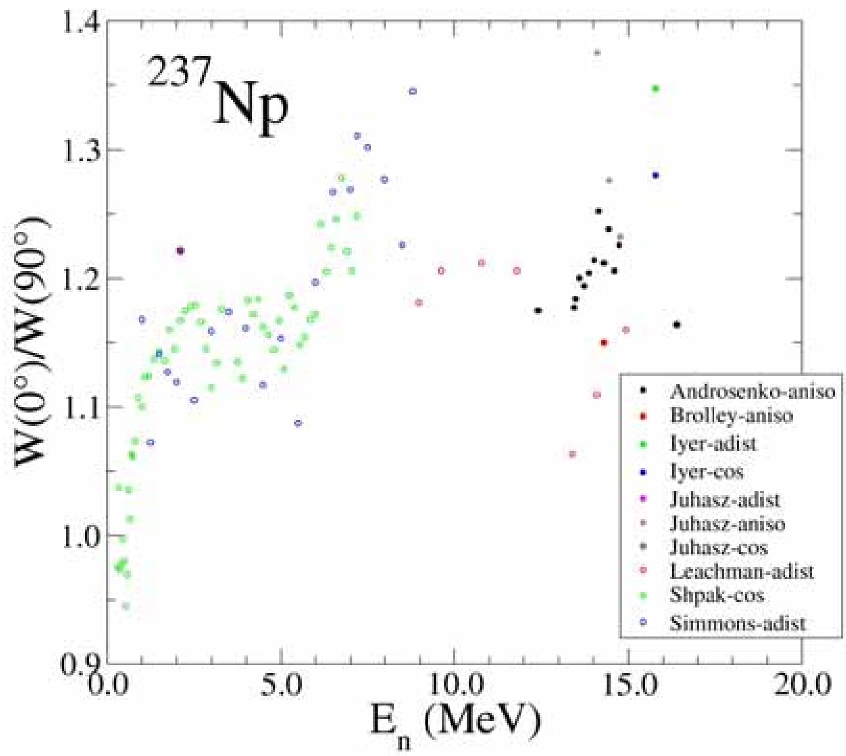

Figure 3 : Angular anisotropy of ^{237}Np, from previous measurements.

Below 10 MeV the results are consistent and show clearly the variation occurring at the first (1 MeV) and second (7 MeV) chance fission, corresponding to transition states of given J and K (total spin and its projection on the fission axis) in ^{238}Np for the first chance and ^{237}Np for the second chance. In the vicinity of 14 MeV several measurements have been performed and they are significantly discrepant from each other. This observation is not specific to this isotope, and the same can be seen for ^{238}U, ^{235}U, ^{233}U, ^{232}Th. Such discrepancies could come from a combination of quick variations of the angular anisotropy, due to the onset of the third chance fission, and an inaccurate knowledge of the neutron energy. In this respect n_TOF is the best facility to solve this problem, because of his very accurate neutron energy determination over an extended energy range.

Above 20 MeV, only one measurement has been carried out for ^{232}Th and ^{238}U [1], and no data exist for the other isotopes. The results from [3] show that a forward anisotropy is persistent up to 150 MeV with an amplitude (1.5 ratio at 70 MeV for ^{232}Th) much higher than in proton-induced fission. Such findings are difficult to explain in the framework of statistical model calculations, peculiarly for the neutron/proton difference in the high energy range. On the other hand we were able to extract from our data the forward part (between 0° and 45°) of the angular distribution for all the isotopes where no significant anisotropy shows up beyond 100 MeV, even for ^{232}Th and ^{238}U.

To summarise, the fission fragment angular distribution of actinides is not well-known above 10 MeV. This is an important information to understand the fission mechanism, in particular to specify the few transition states which are the path to fission. In addition, this angular distribution has an effect in the fission cross section measurements due to the angular limitation of detectors. The size of the associated correction depends on the detecting system, and it is rather significant in our case. Its present uncertainty contributes for 10% in our cross section data for the previous measurements.

Experiment

In a first step we intend to measure the fission angular distribution of ^{235}U, ^{238}U and ^{232}Th in the energy range of interest, in particular where the fission cross section is significant and the angular distribution is known to evolve, namely from 0.3 MeV to 1 GeV, using a modified experimental setup.

We will use a stack of parallel PPACs and targets as we did for the previous cross section measurements. The main modification consists in tilting the stack by 45° with respect to the beam axis, as sketched in Figure 4. This means that the neutron beam will go through the targets and the detectors with this angle of 45°. Therefore for any fission angle it is possible to find an interval of azimuthal angle (around the beam axis) for which the angle of crossing of the backing and detector electrodes is lower than 45°, which is the limit of full efficiency.

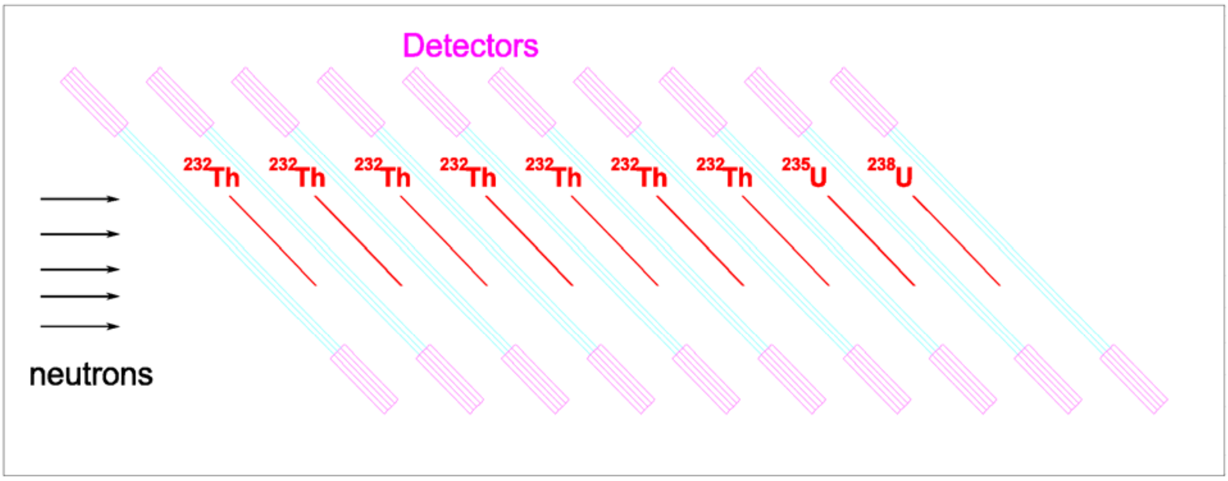

Figure 4 : Top view of the experimental arrangement. The scale is given by the size of the target layer which is 8cm in diameter.

An additional benefit of this arrangement is a rough measurement of the momentum transfer which results in a folding angle of the fission fragments lower than 180°. This angle can be deduced from the apparent forward shift of the target image which is reconstructed with the XY localisations of each detectors.

This geometrical modification needs to rebuild entirely a new reaction chamber due to the higher internal depth of the target and detector assembly. We will take this opportunity to design a modular system allowing different angles of the detectors and targets. Additionnaly, we will make this new device ISO2919 compliant to allow the accomodation of more active targets in the future, in particular ^{233}U, ^{234}U or ^{237}Np.

Beam request

According to our previous experience, we estimate that the total requested number of protons is 1.5 x 10^{18}. This number is similar to the one we used for the cross section measurement of ^{232}Th. It cannot be much lower for two reasons:

- The angular distribution quickly varies around the fission thresholds (1st, 2nd,,, chance) and the number of counts should be enough in small energy intervals to correctly describe those variations.
- The number of clean events for fission angles close to 90° will be reduced due to the restricted range in azimuthal angle

References

[1] L. Tassan-Got et al., ND2004 conference, Santa Fe, New Mexico USA, Sept. 27- Oct. 1, 2004

[2] C. Paradela, PhD thesis, Santiago de Copostela, October 6, 2005

[3] Tutin et al., NIM A457 (2001) 646